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Topography Experiment (TOPEX) Software Document Series

Volume 2
WFF TOPEX Software Documentation Overview

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About the Series

The TOPEX Radar Altimeter Technical Memorandum Series is a collection of performance assessment documents produced by the NASA Goddard Space Flight Wallops Flight Facility over a period starting before the TOPEX launch in 1992 and continuing over greater than 10 year TOPEX lifetime. Because of the mission's success over this long period and because the data are being used internationally to redefine many aspects of ocean knowledge, it is important to make a permanent record of the TOPEX radar altimeter performance assessments which were originally provided to the TOPEX project in a series of internal reports over the life of the mission. The original reports are being printed in this series without change in order to make the information more publicly available as the original investigators become less available to explain the altimeter operation and details of the various data anomalies that have been resolved.

Foreword

This document is an overview of software development activities and the resulting products and procedures developed by the TOPEX Software Development Team (SWDT) at the Wallops Flight Facility (WFF). The SWDT has played a significant role in the Engineering Assessment and Verification Efforts of the TOPEX NASA Radar Altimeter, from pre-launch development to on-going in-flight monitoring.

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Section 1

Introduction

1.1 Purpose

This document provides an overview of software development activities and the resulting products and procedures developed by the TOPEX Software Development Team (SWDT) at Wallops Flight Facility, in support of the WFF TOPEX Engineering Assessment and Verification efforts.

1.2 Scope

This is Volume 1 of a set of six volumes. The other five volumes focus on the software and procedures used to generate the various TOPEX data products. Volume 2 covers the processing of pre-flight test data. Volumes 3, 4, and 5 span the processing of in-flight data, using the three different altimeter data products produced by the TOPEX Ground System (TGS) at the Jet Propulsion Laboratory (JPL), namely the Altimeter Instrument File (AIF), the Sensor Data Record (SDR) and the Geophysical Data Record (GDR). The sixth volume contains documentation regarding special processing performed by the SWDT.

1.3 Organization of Document

Section 2 lists other documents related to the software development activities. Section 3 provides background on the TOPEX/POSEIDON Project in general and on the TOPEX radar altimeter in particular. Section 4 reviews the TOPEX work processes at Wallops Flight Facility. Section 5 discusses the TOPEX software development philosophy. Section 6 describes the processing facilities used at Wallops. Overviews of the SWDT's pre-flight and in-flight activities are provided in Sections 7 and 8.

Section 2

Related Documentation

- TOPEX / POSEIDON Joint Verification Plan , June 15, 1992, JPL92-9.
- TOPEX Mission Radar Altimeter Engineering Support Plan, May 1992, NASA GSFC WFF.
- TOPEX Project Radar Altimeter Development Requirements and Specifications, August 1988, NASA GSFC WFF 672-85-004.
- TOPEX Ground System Algorithm Specification Document, September 1990, JPL D-7075 (Rev. A), TOPEX 633-708.
- TOPEX Ground System Software Interface Specification (SIS-2) Instrument File, October 8, 1991, JPL D-7925 (Rev. A), TOPEX 633-731-23-007, Rev. A.
- Interface Control Document between the TOPEX Ground System and the Goddard Space Flight Center / Wallops Flight Facility Oceans Laboratory, (Rev. 2.0), July 1990, TOPEX 633-712J.
- Wallops Flight Facility TOPEX Project Software Products Specification for Engineering Assessment Software, January 1991.
- Applied Physics Laboratory, TOPEX Radar Altimeter System Specification., APL Document 7301-9028.
- Hancock, D. W., III, 1989, Studies in Support of The NASA Ocean Topography Experiment (Report 1), NASA TM-100766.
- Zieger, Alfred R., David W. Hancock, III, George S. Hayne, and Craig L. Purdy, June 1991, NASA Radar Altimeter for The TOPEX / POSEIDON Project, Proceedings of The IEEE, Vol. 79, No. 6, pp. 810-826.
- Marth, P. C., J. R. Jensen, C.C.Kilgus, J. A. Perschy, and J. L. MacArthur of The Johns Hopkins University Applied Physics Laboratory; D. W. Hancock, III, G. S. Hayne, C. L. Purdy, and L. C. Rossi of NASA GSFC WFF; and C.J. Koblinsky of NASA GSFC, Pre-Launch Performance of the NASA TOPEX / POSEIDON Altimeter, IEEE Transactions on Geoscience and Remote Sensing, 31(2), pp. 315-332, 1993.
- Hancock, D. W., III, R. L. Brooks and H. A. Goldberg, June 1992, Performance Parameters for The TOPEX Radar Altimeter from Bench Testing through Spacecraft Thermal Vacuum Testing, NASA GSFC WFF.
- Hancock,D.W.,III, G.S.Hayne, C.L.Purdy, J.B.Bull, and R.L.Brooks, 1992a, TOPEX NASA Altimeter Operations Handbook, WFF TOPEX Internal Publication WFF-TPX-005.
- Hancock,D.W.,III, R.L.Brooks, and H.A.Goldberg, 1992b, Performance Parameters for the TOPEX Radar Altimeter from Bench Testing through Spacecraft Thermal Vacuum Testing.

- Hancock,D.W.,III, C.L.Purdy, G.S.Hayne, and R.L.Brooks, 1994, TOPEX Mission Radar Altimeter Engineering Assessment Report.

Selected documents and memos are also included in Appendix F-Attachments for completeness.

Section 3

Background

3.1 TOPEX/Poseidon

Launched on August 10, 1992, the TOPEX / POSEIDON satellite is a joint U.S. and French effort being conducted by the two respective space agencies, the National Aeronautics and Space Administration (NASA) and the Centre National d'Etudes Spatiales (CNES), to develop and operate an earth-orbiting satellite with sensors capable of making precise and accurate measurements of sea level. The objective of the mission is to measure the sea level in such a way that allows the study of ocean dynamics, including the calculation of the mean and variable surface geostrophic currents and the tides of the world's oceans.

The primary instruments on the TOPEX / POSEIDON satellite are a NASA dual-frequency altimeter and a CNES solid-state altimeter. Instruments to provide auxiliary measurements to allow for corrections to the altimeter measurements and for determining the precise orbit of the satellite are included.

The Johns Hopkins University Applied Physics Laboratory (JHU / APL) developed the NASA altimeter hardware for NASA's Goddard Space Flight Center / Wallops Flight Facility (WFF). The TOPEX altimeter was integrated into the TOPEX / POSEIDON spacecraft by Fairchild Space (FS) Company. The project is managed by the Jet Propulsion Laboratory (JPL). Figure 3.1 shows an illustration of the TOPEX / POSEIDON spacecraft.

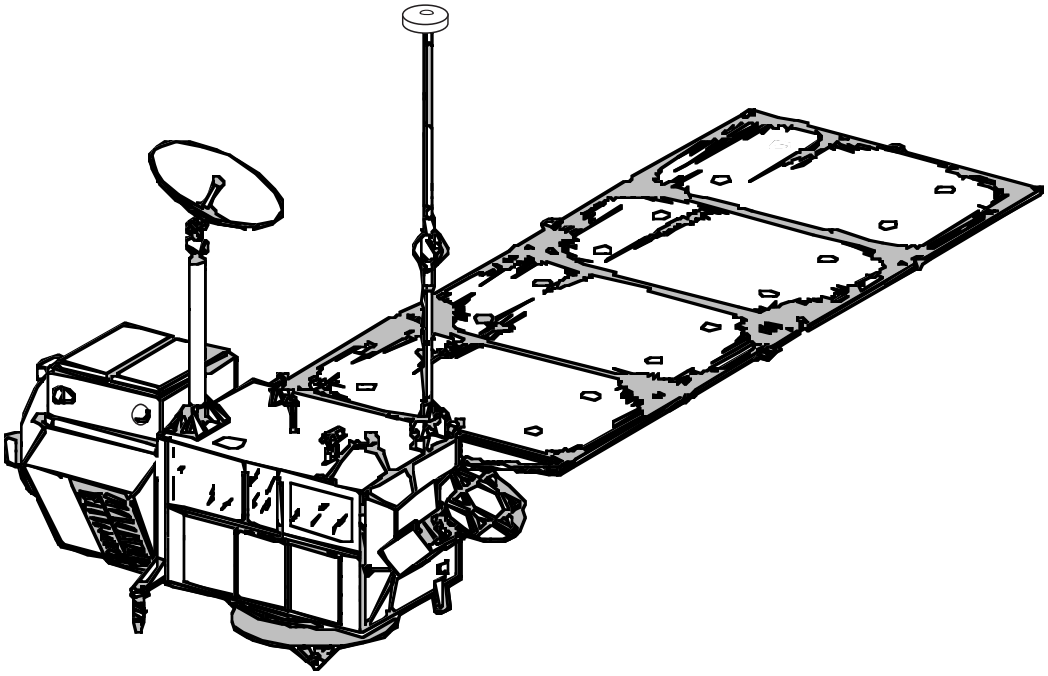

Figure 3-1 The TOPEX/Poseidon Spacecraft

3.2 NASA Radar Altimeter (ALT)

The NASA Radar Altimeter (ALT) is a dual-frequency radar altimeter whose design evolved from a number of previous altimeters (for example, Seasat and Geosat). The ALT was designed with complete redundancy of all active circuitry. It is a nadir-looking radar which transmits RF energy towards the earth's surface, then receives and processes the reflected energy. It measures height of the altimeter above the earth's surface (pulse transmit time), ocean significant waveheight (via return pulse shape characteristics), and surface radar backscatter coefficient (via received energy). A significant design change from previous altimeters is the inclusion of a second frequency (thus dual-frequency) to yield information on propagation delay due to ionospheric effects. Figure 3.2 displays Radar altimeter measurement effects. Figure 3.3 describes information received from the radar pulse.

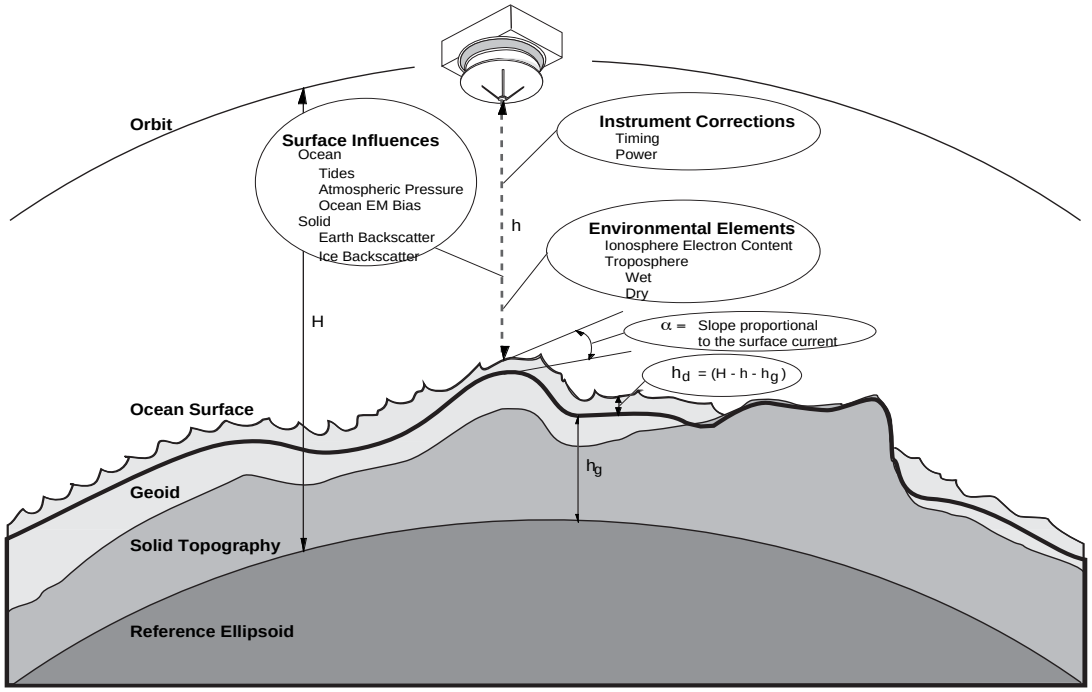

Figure 3-2 Radar Altimeter Measurement Effects

The altimeter can be commanded into several modes of operation. Table 3.1 describes each mode. The normal operating mode of the altimeter is FTRK. Twice a day, however, the altimeter is commanded into CAL mode for internal calibration purposes. When the CNES altimeter is operating, the NASA altimeter is commanded into the IDLE mode.

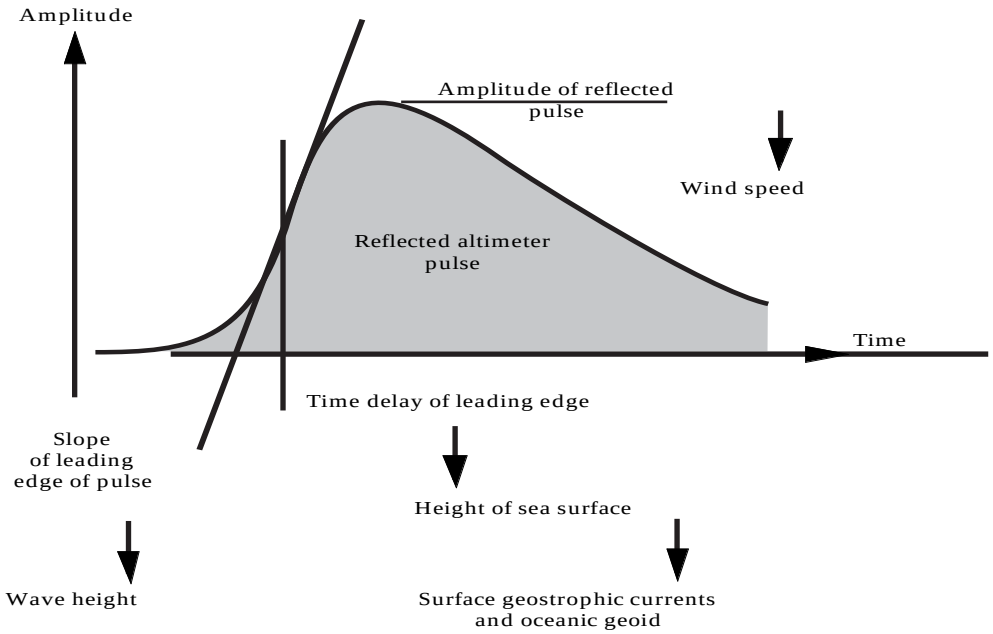

Figure 3-3 Information in the Reflected Radar Pulse

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Mode	Definition
OFF1	The spacecraft power system is not applying 28 volts to the radar altimeter. The spacecraft power bus relay to the altimeter is open.
OFF2	The spacecraft power system is applying 28 volts to the radar altimeter, but all systems within the altimeter are in the OFF state. The internal altimeter relays are open. Power is supplied to the charging capacitors.
IDLE	The altimeter does not transmit. Primarily used when the CNES altimeter is on.
STBY	The altimeter does not transmit.
CAL1	CAL-I is the first of two internal calibration modes. The transmitted pulse is fed back to the altimeter through a series of attenuators in 17 discrete steps. Provides monitoring of height bias, total loop gain characteristics, and waveform sample operations.
CAL2	This is the second of two internal calibration modes. CAL-II is a single-step process wherein the AGC operates on noise only. Provides receiver and waveform characteristics.
CACQ	Coarse Acquisition is the first of four track modes. The flight software searches for a return signal from the surface in low resolution (50 ns pulsewidth).
CTRK	Coarse Track is the second of four track modes. Surface return waveforms are tracked in coarse resolution.
FACQ	Fine Acquisition is the third of four track modes. After a signal is detected in coarse resolution, fine resolution acquisition (3.125 ns) begins. If the tracking performance in the Coarse Track mode is of sufficient quality, this step is omitted and the altimeter goes directly to Fine Track mode.
FTRK	Fine Track is the last of four track modes. Surface return waveforms are Fine Track is the last of four track modes. Surface return waveforms are tracked in fine resolution. This is the normal operating mode.

Section 4

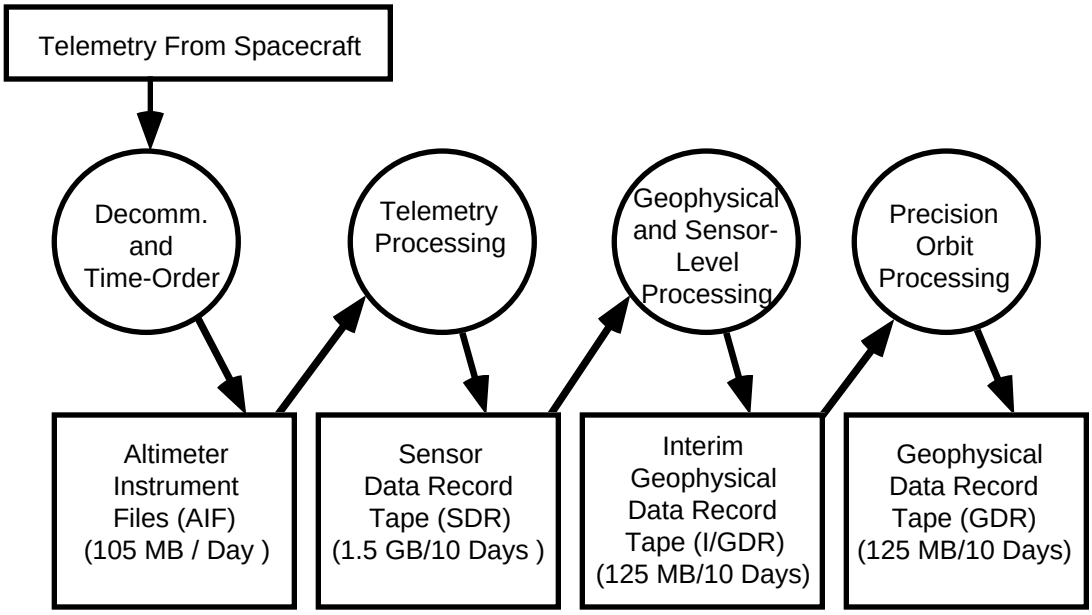
WFF Work Processes

4.1 Data Flow

The TOPEX data are telemetered in two streams, the engineering stream and the science stream. The engineering stream, transmitted approximately every eight seconds, includes measurements such as temperatures, voltages, and internal status parameters. The science stream, which is transmitted at approximately one-second intervals, includes such measurements as Ku heights, C-minus-Ku height differences, significant waveheight voltage, waveform samples, and Automatic Gain Control values (signal strength measurement).

TOPEX Altimeter science and engineering data streams are received at the Jet Propulsion Laboratory (JPL) and processed by the TOPEX Ground System (TGS) into Altimeter Instrument Files (AIFs). The TGS processes the AIF by running Telemetry-level algorithms and earth-location processing to create Sensor Data Record (SDR) files. Sensor and Geophysical-level algorithms are run by the TGS on SDR files to create Interim Geophysical Data Record (IGDR) files. Once precision orbit data are received, the new navigation data are merged in and the IGDRs become Geophysical Data Records (GDRs). Figure 4.1 shows the TOPEX data flow.

Figure 4-1 TOPEX Data Flow



4.2 Engineering Assessment Effort

The WFF Engineering Assessment (EA) effort is dedicated to establishing that the satellite, sensors, communication links, and ground equipment are functioning properly. EA began while the altimeter was being developed to verify that the altimeter met the required specifications and to provide a baseline of measurements to be used for in-flight monitoring.

4.3 Verification Effort

The requirement for verification of the NASA altimeter geophysical measurements is to show that the measurements and parameters calculated from the measurements are accurate to the specified levels. Verification support by WFF of the geophysical measurements and science data products began before launch and continues throughout the mission. Pre-launch activities consisted of development of verification hardware and software and testing to ensure that the ground data system was ready to receive and process satellite sensor, tracking, and in situ data. Throughout the mission there is a continuing monitoring activity which performs checks on the data to detect any significant change in the data quality or accuracy.

4.4 Algorithm Development Effort

WFF developed 24 of the algorithms used in the TGS processing. An overview of the Wallops algorithm development process for TOPEX is provided by Forsythe (1993).

The SWDT implemented and tested these algorithms, along with several other, JPL-developed, algorithms used in TGS processing. This implementation process, which occurred pre-launch, allowed the algorithm developers to assess the adequacy and appropriateness of each algorithm, and to obtain information about any implementation problems. For WFF's ongoing engineering assessment process, these implemented algorithms are used to process real or simulated data, in order to address and evaluate aspects of the altimeter's performance.

Section 5

WFF Software Development

5.1 Philosophy

The WFF Software Development Team (SWDT) uses a variety of tools and techniques to develop and maintain the TOPEX software. The software development philosophy is based on rapid prototyping and high user / customer / developer interaction. Change control is implemented where appropriate. Commercial off-the-shelf (COTS) software is employed to ease development and reduce unnecessary effort. The SWDT development methodology has produced highly-specialized software tools and processes that are sufficiently automated to handle standard processing tasks and yet flexible enough to assist in highly-detailed investigations.

This approach allows the customer to modify requirements as development proceeds and the developer to code the software for maximum reusability and ease of use. The rapid prototyping approach was necessitated by the constraints of a research and development environment. Software used for research and development must be highly flexible to meet unanticipated needs. The TOPEX software and its success record validate the rapid prototyping philosophy.

5.2 Development

Software development takes place in both Macintosh and UNIX environments. Much of the FORTRAN software was developed on the Macintosh and ported to UNIX for processing speed. The porting process has two benefits: it has enabled the SWDT to find problems in the code on one platform that did not show up on the other and it has ensured that the software is highly portable. The use of IDL software, in a UNIX-based graphics development environment, has allowed the SWDT to automate the time-consuming process of producing standard plots. TOPEX databases are kept in the Macintosh environment since the COTS database software, FoxBase, is unavailable for UNIX. Most of the COTS software used in the TOPEX effort resides in either the Macintosh or MS-DOS environments.Apple Macintosh Workstations

5.3 Change Control

Phase 1: Investigation

Investigation, the first phase of the change control process, is initiated by a normal TOPEX Request. This request clearly notes that work involved may be a new standard process or impact existing change control software. The request should state the new or modified requirement and allow the SWDT to work with the requester in order to clarify requirements, begin prototyping solutions, and running test cases. Meetings with the WFF TOPEX Team may be necessary. Upon completion of this request, the requester should make a no / no-go decision regarding implementation.

Phase 2: Implementation

Implementation, the second phase of the change control process, is initiated by the requester in the from of a Software Change Request and passed through the TOPEX Task Leader. The software change request must be approved by the TOPEX Team and signed by the Software Manager. Upon implementation, the change request is closed and a Software Change Notice describing dates, versions, and affected products is distributed.

Section 6

WFF Processing Facilities

6.1 Communications

WFF TOPEX facilities are connected via Observational Science Branch NETwork (OSBNET) to the Wallops Flight Facility Campus network, which is connected to the NASA Science Internet (NSI) and the Internet via a Proteon router. Extensive use is made of OSBNET and the Internet for data transfer, remote monitoring, and electronic mail. The OBSNET communications network is depicted in Figure 6.1

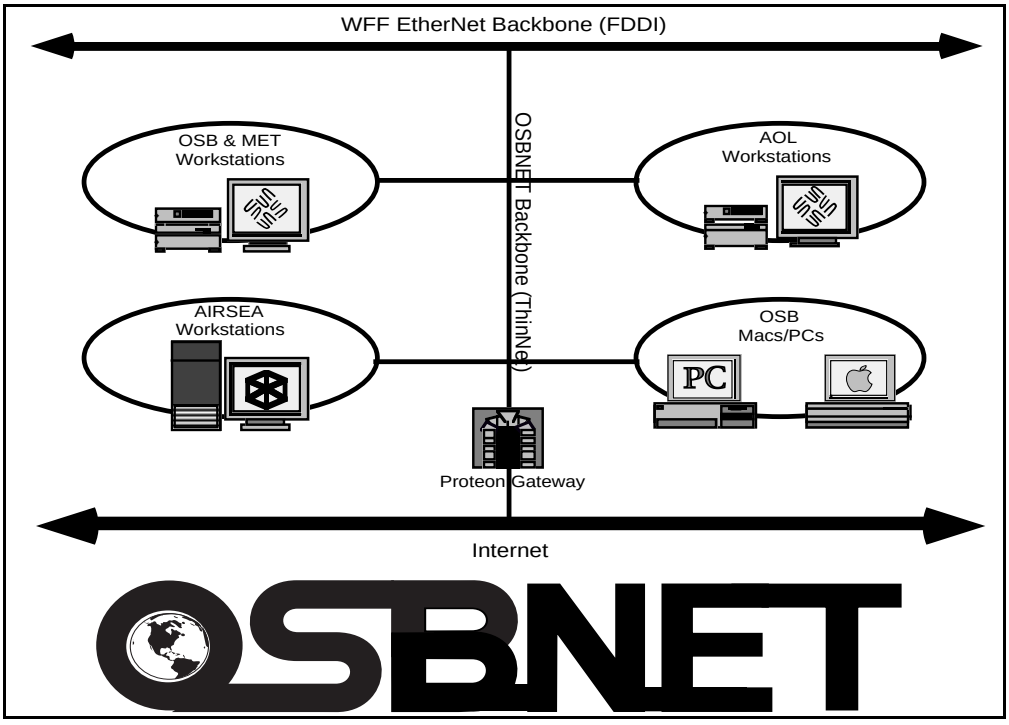


Figure 6-1 OSBNET

6.2 Sun SPARC Workstations

A Sun SparcStation 10/30, osb3.wff.nasa.gov (osb3), handles most of the WFF TOPEX processing and storage. osb3 is based on a 36MHz TI SuperSPARC processor and is loaded with 64MB of memory and 5.278 GB of disk space, of which 4.283 GB are dedicated to TOPEX. Exabyte and DAT tape units are both installed. See Table 6.1 for a breakout of osb3's TOPEX-dedicated file systems.

Table 6-1 osb3 TOPEX File System Structure

Directory	Comments
/gen/topex (414MB)	Contains home directories for WFF TOPEX personnel.
/gen/topex2 (1968MB)	Primary TOPEX Processing directory
/gen/topex2/aif	Working area for AIFs. Also temporary storage area for newly-received AIFs.
/gen/topex2/bin	Contains executables and UNIX scripts.
/gen/topex2/cnesigdr	Contains SSALT IGDR files from Aviso CDROM.
/gen/topex2/datafiles	Contains datafiles used by WFF processing.
/gen/topex2/dbase	Temporary storage area for merged database import files.
/gen/topex2/idl	Contains IDL programs.
/gen/topex2/igdr	Working area for IGDR files.
/gen/topex2/igdr/incoming	Temporary storage area for newly-received IGDR files.
/gen/topex2/lib	Contains WFF TOPEX FORTRAN libraries.
/gen/topex2/orf	Contains latest Orbit Rev Files retrieved from JPL.
/gen/topex2/rase	Working area for RASE files.
/gen/topex2/sdr	Working area for SDR files.
/gen/topex2/src	Contains WFF TOPEX FORTRAN source code.
/gen/topex2/str	Working area for STR files.
/gen/flight (1590MB)	Primary TOPEX Storage directory.
/gen/flight/aif	Storage area for newly-received AIFs. Later moved to Exabyte.
/gen/flight/igdr	Storage area for newly-received IGDRs. Later moved to Exabyte.
/gen/flight/sdr	Storage area for newly-received SDRs. (no longer used)
/gen/tempsdr (311MB)	Temporary storage area for external users.

osb3's operating system is Solaris 2.x, a multiuser SYSVR4-based version of UNIX. Full TCP / IP capabilities such as Telnet, FTP, NFS, and Internet-style electronic mail are integrated into the operating system. SparcWorks FORTRAN and C are used for development, and Research Systems Incorporation's IDL is used for plotting. An Internet connection and dialup modem lines provide internal and external access.

6.3 Apple Macintosh Workstations

An Apple Macintosh Quadra 900 is used for the TOPEX Database System and software development. The Quadra 900 is based on a 20MHz Motorola 68040 processor and is loaded with 36MB of memory and 1GB of disk space. 400MB of disk space is

dedicated to TOPEX database support. The Quadra 900 is connected to the Wallops Campus Network and the Internet.

The Quadra runs Apple's System 7.x operating system. Intercon's NFS/Share software is used to facilitate NFS data exchange between the Quadra and osb3. Intercon's TCP/Connect II is used to provide Telnet and FTP services. CE Software's QuickMail provides local mail service and a MailLink/SMTP bridge serves as a UNIX/SMTP to QuickMail mail gateway. Apple's Macintosh Programmers Workshop and Language System's FORTRAN are used for software development. Microsoft FoxBase/Mac is used as the relational database environment, and custom software has been written to ease the most commonly used database features.

6.4 Commercial-Off-The-Shelf Software

The Quadra, and other Macintosh and MS-DOS computers, are available for special processing using Commercial Off The Shelf (COTS) software. Currently, such COTS packages as Abacus StatView II, Microsoft Excel, and Informix WingZ are used for special analysis. Deneba Canvas and Microsoft Word are used for documentation.

Section 7

Pre-Flight Activities

The SWDT has played an active and multi-faceted role in WFF's TOPEX mission of performance assessment and verification. Prior to launch, its software development was key to establishing an altimeter performance data base and to evaluating the algorithms being developed for the TOPEX altimeter. Its pre-flight activities included the following:

- Developed software to read the magnetic tape data stream coming from pre-launch altimeter testing. The software development was based on the format of the science frames and engineering frames, as delineated in the TOPEX NASA Altimeter Operations Handbook (Hancock, et al, 1992a).
- Developed and maintained a data base of the testing results, from which a measurement history became available. Performance parameters were thereby generated for the TOPEX radar altimeter, from bench testing through spacecraft thermal vacuum testing (Hancock, et al, 1992b). These statistics were then used by the altimeter engineers to compare the altimeter performance with the pre-build specifications, to compare test-to-test results, and to establish a baseline for on-orbit performance.
- Developed and refined techniques for quickly producing special-use software. This capability permitted fast response to work requests.
- Developed a semi-automatic method of plotting the performance parameters. These plots were invaluable in assisting the NASA and APL altimeter engineers in interpreting and understanding the sensor's status and responses to particular testing conditions.
- Established baseline references for the altimeter's internal calibration data base.
- Developed the automatic production of altimeter measurement logs which denoted, among other items, times of status changes, command changes, and reset times.
- Created summary plots of high-rate and low-rate waveforms, thus facilitating the study of waveform structures.
- Coded and implemented the WFF-developed algorithms. Test data and simulated data were input to the coded algorithms, to evaluate the appropriateness of the algorithms.
- Developed software to create or edit command files and to modify parameter files for the altimeter.
- Developed enhanced techniques to send and retrieve files from the TOPEX work areas at JPL.

- Established a software and document library, with electronic entry and search capabilities.
- Established a pre-flight testing performance library of data logs, performance statistics, and data plots.
- Established an archive of altimeter data tapes.

Section 8

In-Flight Activities

Subsequent to the launch and initial turn-on of the TOPEX altimeter, the SWDT has continued to play a pivotal role in WFF's TOPEX mission of performance assessment and verification. The Team has enhanced its software capabilities, and is one of the keys to WFF's achievement of monitoring the altimeter performance at the sub-centimeter level. Its inflight activities have included the following:

- Placed the software system under configuration control, to assure continued integrity of the output data. Changes to the software are permitted, but only after a formal review and approval of the recommended change. As a result, the software changes and their rationale have been well documented. Whenever a software change has changed the internal data consistency (e.g., a change in a reference), the entire inflight data base has been reprocessed.
- Developed and has maintained an (I)GDR data base of inflight measurements from launch to the present. When this information is appended to the prelaunch data base, a combined total of more than eight years of data are available for the TOPEX radar altimeter.
- Adopted the use of IDL software to facilitate the plotting of parameters.
- Provides GDR pass plots for each cycle. Each plot includes the pass groundtrack superimposed on a map, the altimeter status as a function of time, and plots of key measurements.
- Provides standard altimeter performance assessment products on a daily, weekly, and periodic basis; the products are listed in Table 8.1. They allow the NASA altimeter engineers to stay abreast of the altimeter's status. Examples of these products are in the TOPEX Mission Engineering Assessment Report (Hancock, et al, 1994, with subsequent yearly updates).
- Continued the automatic production of altimeter measurement logs which denoted, among other items, times of status changes, command changes, and reset times.
- Developed a screen display such that real-time POCC mission operations screens are available at Wallops. This greatly facilitates monitoring by WFF altimeter engineers of command file uploads.
- Developed enhanced techniques to send and retrieve files from the TOPEX work areas at JPL. One of the techniques involves an automatic periodic interrogation of the WFF assigned file space at JPL, to transfer AIF files to Wallops as soon as they are available.
- Expanded the contents of the software and document library, and enhanced the library's electronic entry and search capabilities.

- Continued adding to the library of data logs, performance statistics, and data plots.
- Continued the archive of altimeter data tapes. Since launch, the data media have evolved from 9-inch magnetic tapes to exabyte tapes and, most recently, to dat tapes.

Table 8-1 TOPEX Standard Altimeter Performance Assessment Products

daily	topex daily aif summary information
weekly	launch-to-date instrument files (cal, waveform, eng. plots)
periodically	seu listing w/plots i/gdr cycle summary plots gdr pass plots i/gdr launch-to-date (cal corrected and edited)

Abbreviations & Acronyms

AIF	Altimeter Instrument File
ADP	Algorithm Development Plan
ADT	Algorithm Development Team
AGC	Automatic Gain Control
APL	Applied Physics Laboratory
CAL	Calibration Mode or Calibration Mode data
CSC	Computer Sciences Corporation
CNES	Centre National d'Etudes Spatiales
COTS	Commercial Off-The-Shelf
EM	Electromagnetic
ENG	Engineering Data
EU	Engineering Unit
FTP	File Transfer Protocol
GDR	Geophysical Data Record
GSFC	Goddard Space Flight Center
HDR	Header data
IGDR	Intermediate Geophysical Data Record
IDL	Interactive Data Language
JPL	Jet Propulsion Laboratory
NASA	National Aeronautics and Space Administration
NSI	NASA Science Internet
RASE	Radar Altimeter System Evaluator
SCI	Science Data
SDR	Sensor Data Record
SDS	Science Data System
SIS	Software Interface Specification
SDT	Science Definition Team
SEU	Single Event Upset
STR	Selected Telemetry Record

SWDT	Software Development Team
SWH	Significant Wave Height
TGS	TOPEX Ground System (TGSA, TGSB, & TGSC VAX Cluster)
TMR	TOPEX Microwave Radiometer
TOPEX	Ocean Topography Experiment
UTC	Universal Time Coordinated
WFF	Wallops Flight Facility